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RESEARCH DIRECTED TOWARD THE USE OF LONG AND INTERMEDIATE PERIOD SEISMIC WAVES FOR THE IDENTIFICATION OF SEISMIC SOURCES

Tosimatu Matumoto

Lamont-Doherty Geological Observatory

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by

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Palisades, New York 10964

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13. ABSTRACT

Seismological research supported by Air Force contract F-19628-71-C-0245 at the Lamont-Doherty Geological Observatory is summarized for the period 1 January 1972 to 30 June 1972.

During this period extensive analysis was continued on the systematic regional variations in stresses. Areas in which high stress earthquakes tend to occur were uncovered. Several Tibetan earthquakes for which M_s-m_b values are close to those of explosions were studied.

The seismic signals generated from nuclear explosions in the Aleutian Islands have been used extensively to study the regional change of structure and relocating Aleutian earthquakes, and to provide a better means of detection and identification of the events in that area.

The effect of lateral inhomogeneities implied by plate tectonics on the generation and propagation of seismic waves is being explored. In island arc regions, mid ocean ridges and oceanic fracture zones these processes are becoming well understood, but in regions of continental collision and intraplate seismicity, less is known. Evidence is accumulating, however, from Asia, Africa and Eastern North America to illuminate the effects of tectonics on seismicity and propagation in these regions.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Plate tectonics						
Intraplate seismicity						
Core phases						
Shear velocity						
Attenuation						
Hinge faulting						
Transform fault						
Residual						
Rayleigh wave						
Tectonic						
Focal mechanism						
Strike-slip						
Compressive stress						
Plate boundary						
Love wave						

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MAJOR SCIENTIFIC ACCOMPLISHMENTS

In the following paragraphs, scientific accomplishments are summarized following the itemization in the statement of work of this contract.

Line - Item 1a

Operation of the world-wide Lamont-Doherty network of long- and intermediate-period seismic stations at the Palisades (PAL), Sterling Forest (SFC), and Ogdensburg (OGD) continued during the present contract period.

Line - Item 1b

Two studies on core phases were made during this period. Core phases have prominent frequencies near 1 second, and usually exhibit an isolated seismic signature, which feature is similar to that of long-distance explosion signals.

1. Core phases from three Philippine earthquakes have been studied in the distance range from 110 to 130 degrees using long period WWSSN seismograms. Theoretical seismograms were computed for each of these events, assuming different core models. Corresponding amplitudes in the observed and the theoretical seismograms were compared either by constructing amplitude-distance curves or by forming the amplitude ratio of a core phase and the diffracted P wave at the same distance. Preliminary results of this comparison are the following:

(1) There is no observed GH branch in the distance range from 120 to 130 degrees. On the other hand, models of the core like Bolt's produce observable amplitudes there. Hence, the transition zone from the outer to the inner core cannot be separated from the outer core by a more or less discontinuous change in physical parameters. It is more probable that there is a gradual change. The observed short period GH arrivals could be due to local inhomogeneities.

(2) Traditional values of the P velocity variation $\Delta\alpha$ across the inner core boundary of 0.9 to 1 km/sec necessarily lead to shear velocities β_{1c} at the top of the inner core of 5 to 6 km/sec. Even then, the agreement between observed and theoretical seismograms is not very good.

(3) Reduction of $\Delta\alpha$ to 0.6 km/sec which is compatible with short period amplitude data leads to β_{1c} values between 3 and 4 km/sec, and the agreement between observed and theoretical seismograms is much better. Changes in the density variations $\Delta\rho$ give only minor changes in β_{1c}.

2. Investigation of precursors to the seismic phases PKPPKP has been continued. In order to explain the short-period observations, a reflecting horizon within the upper mantle does seem to be required at a depth of 650 km. A paper entitled "Seismic waves reflected from velocity gradient anomalies within the Earth's upper mantle" has been submitted (February, 1972) to the journal "Zeitschift für Geophysik."

Line - Item 1c

Extensive studies of plate tectonics at various regions have been continued. Emphasis is placed on regional differences in velocity and attenuation. Of the greatest interest, however, are the regions of high-stress drop. Some of the Tibetan earthquakes show that M_s-m_b values are close to those of explosions, and may present problems in discrimination.

1a. Sykes has examined the location and possible depths of several earthquakes in Tibet for which M_s-m_b values are close to those of explosions. He finds that these earthquakes are located on or very close to the Indus suture zone, the position at which the Indian plate is thought to have collided with northern Eurasia. These earthquakes are located at the eastern end of the Himalayan arc where it terminates against structures with a northerly strike in Burma. A similar zone of earthquakes is found at the western end of the Himalayan arc where it meets north striking features in Pakistan. The latter intersection occurs in the Hindu Kush where abundant intermediate focus activity is found. A well-defined dipping seismic zone is present beneath the Hindu Kush for depths from about 150 to 250 km. Russian workers have found that intermediate depth earthquakes in the Hindu Kush suffer very little attenuation when they travel to their instruments in the Garm region just to the north of the Hindu Kush. Seismic rays travelling upwards through the diffuse zone of earthquakes above the Hindu Kush source suffer greater attenuation. The well-defined zone of intermediate depth earthquakes in the Hindu Kush is thought to represent the last remnant of ocean crust that was consumed when India collided with Eurasia. The Tibetan zone at the other end of the Himalayan arc may also be the site of sub-crustal earthquakes or a region of high stress related to hinge faulting at the end of the arc. Thus, the best explanation for the M_s-m_b anomaly for the Tibetan earthquakes is that these shocks are somewhat deep (i.e., about 50 km) or that they are a high stress drop associated with the thrusting of two continental plates or associated with hinge faulting at the end of the arc.

Plate tectonics has so far been very successful in explaining many features of island arcs, mid-ocean ridges, and transform faults. To date, it has been less successful in explaining continental collision which is apparently occurring in the broad zone north of the Himalayas and across central Asia. A great deal of geological information, however, can be brought to bear upon the problem of plate tectonic interactions in this area. It is perhaps not surprising that either high stress drop earthquakes or earthquakes with a depth of 50 to 70 km may occur in this region and may present problems for discrimination on an M_s-m_b basis. The Tibetan events are some of the largest known earthquakes for which the M_s-m_b values are similar to those of underground explosions.

2. P-travel times of the CANNIKIN nuclear explosion were studied using NOAA and Lamont seismic data along the Aleutian island arc and in Alaska. Eastward from the shotpoint J-B residuals increase from -2 sec to -6 sec along the arc from Adak to Kodiak. A north-south change in residuals was observed with small negative residuals (-2 sec) in central Alaska and high negative residuals (-6 sec) near the Gulf of Alaska. CANNIKIN P-residuals were 1 to 2 seconds more negative than those of the LONGSHOT nuclear explosion. The interpretation of the observed residual pattern indicates a continental velocity structure in the wedge above the high velocity slab and beneath the ridge that is located between the trench and the active volcanoes. This velocity structure was previously obtained from teleseismic P-wave and surface wave data, and is similar to a structure usually encountered beneath an orogenic belt. The effect of various station distributions on the relocation of CANNIKIN was investigated, to find a better means of relocating Aleutian earthquakes.

3. Travel times and frequency content of seismic P waves from nuclear explosions and of P and S waves from Aleutian earthquakes have been analyzed to derive seismic velocities and attenuating properties of the crust and upper mantle beneath and adjacent to the Aleutian island arc. The body wave data are supplemented by Rayleigh wave dispersion data for paths along the arc towards a station on Amchitka Island. Three main tectonic features can be distinguished: 1) The high-Q high velocity slab of the underthrust Pacific plate. 2) A thickening of the oceanic crust in the overthrust Bering Sea plate beneath the island arc ridge between the trench and volcanic line with a velocity structure almost identical to that for a continental margin. 3) A zone of moderately anomalous low velocities and Q in the mantle beneath the Bering Sea Abyssal Plain for ray paths between the arc and a station on St. Paul Island. This zone appears to be just north of the volcanic line. Its depth and lateral extension, however, are not well defined from the presently available data. The low-Q, low velocity zone beneath the Bering Sea is not as well developed as beneath presently active zones of ocean floor extension in some interarc basins, e.g. the Lau basin behind the Tonga arc.

4. A recently developed method of three-dimensional seismic ray tracing is employed to reinterpret P-wave travel-time residuals of the Longshot nuclear explosion on Amchitka, Aleutian Islands, in terms of plate tectonic structure near the source and near the teleseismic stations. The observed pattern of P residuals from Longshot can be explained by an 80 km thick, descending lithospheric plate that reaches a depth of 250 km beneath the Aleutian arc, and has 7% to 10% higher P-wave velocities than the surrounding mantle. The anomalous high velocity at 100 to 200 km depth indicates that the descending plate at that depth is colder than the surrounding normal mantle by several hundred degrees.

The P travel-time anomaly associated with the dipping plate is eliminated from the total P residuals to obtain new worldwide station residuals. The station residuals are then grouped according to a proposed tectonic code that distinguishes between active zones of plate convergence, divergence, and transcurrent shear as well as between volcanically active regions and stable oceanic and continental regions. The tectonically grouped station residuals show a strong correlation with various tectonic features. On the average P arrivals in continental shields are earlier by 1 second

than in younger (but stable) continental and oceanic provinces, and earlier by 2 seconds than in active volcanic regions. The station residuals indicate that lateral velocity anomalies within the upper 200 to 250 km of the earth's mantle are commonly associated with tectonic features and that lateral velocity contrasts may in some cases exceed 10% of the average velocity. A new P-residual map for the United States and adjacent Canada is presented.

5. The group velocities of Rayleigh waves in the period range from 20 to 60 seconds were analyzed from records of a seismic station operated on Amchitka Island using seismic events in the South Pacific, Japan, the Kuril-Kamchatka region, and from along the Aleutian Arc. The original mixed-path group velocity data were separated into pure oceanic-path and pure ridge-path group velocities. Throughout the entire period range group velocities for the Aleutian ridge were found to be consistently by at least .3 km/sec slower than for the oceanic regions in the Pacific. Systematic inversion of the group velocity data indicates that the S velocity in the upper 120 kilometers of the mantle beneath the ridge and above and adjacent to the inclined seismic zone are lower by nearly 10% than in a normal oceanic mantle and that the crust beneath the ridge is almost 30 kilometers thick, typical for and similar to the crust and upper mantle structure of a young continental orogenic belt.

6. Focal mechanisms are presented for earthquakes located along the Near Islands and Commander Islands for the western Aleutian Archipelago and along the northeast coast of the Kamchatka peninsula. Along the southern slope of the Aleutian ridge mechanisms indicate shallow angle thrusting with a slip vector parallel to the trend of the ridge striking N50°W. Along the northern slope of the Aleutian ridge, the area between the Near Islands and the western slope of the Shirshov ridge is currently aseismic, but west of the Shirshov ridge a zone of right lateral strike slip mechanisms occur along a well defined bathymetric escarpment. Strike slip motion along the trend of these zones occurs as far west as 165°E midway between the contours defining the end of the Aleutian ridge and the beginning of the Kamchatka peninsula. Mechanisms along the Kamchatka peninsula near the Aleutian ridge junction define three tectonic zones. North of the junction, between 58°N and 56°N, mechanisms at moderate angle thrusting with a component of strike slip motion with a slip vector the same as that along the Aleutian ridge. At the junction, between 56°N and 54°N there is no longer a component of strike slip motion. South of 54°N thrusting occurs at shallow angles perpendicular to the coast of Kamchatka.

7. Historical seismicity studies of the eastern section of Canada and northeastern United States indicate the existence of a seismic belt trending in a northwesterly direction and passing through Boston and Ottawa. This zone coincides with the White Mountain magmas, the Monterregian hills and the Ottawa-Bonnachere graben. Portable seismographs were used to supplement the permanent stations of the Lamont-Doherty seismic net for the recording of the first arrival from the Cannikin nuclear explosion. The stations were set up across the above seismic belt and adjacent areas. Arrivals from these stations show early arrivals with respect to a Jeffreys-Bullen earth, residuals ranging from (4.2 to 6.8 sec). All stations inside the seismic belt

show larger (6.0 to 6.8 sec) residuals than stations outside the belt (4.2 to 5.8 sec). These residuals were compared with residuals calculated from a model that utilizes a dipping slab under the Aleutian chain. The effect of this model does not significantly alter the above residuals. The relative difference in residuals on either side of the seismic belt can be explained by differences in the crust and upper mantle under this area, possibly a result of magmatic activity during the Jurassic and Cretaceous. The seismic anomalies suggest that a weak zone may exist in the North American plate. This weakness may allow stress in the plate to be relieved in the form of earthquakes localized around the zone of weakness.

8. A large region of high horizontal compressive stress is delimited in eastern North America from a combination of fault plane solutions of earthquakes, in situ stress measurements, and geologic observations. Each of these methods, including in situ stress determination by both overcoring and hydrofracturing, yield nearly identical directions for the principal stresses. The maximum compressive stress trends east to northeast over an area extending from west of the Appalachian Mountain system to the middle of the continent, and from southern Illinois to southern Ontario. In this region earthquakes appear to occur in regions of high stresses along weak zones in the lithosphere. An example of such a weakness is the seismic belt trending from Boston to the northwest through Ottawa. This seismic zone appears to be located along a continental extension of the Kelvin seamount chain which is postulated by others to be a fracture zone related to the early opening of the North Atlantic. Similarly the 1929 Grand Banks earthquake and the Charleston, S. C. seismic trend appear to be along extensions of other oceanic fracture zones.

The relationship between high stress and weak zones may provide a means to assess the earthquake risk within plates. The observed pattern of stresses appears to be Mesozoic or later in origin, and does not seem to be significantly influenced by glacial rebound. This work supports Voight's hypothesis that the compressive stress observed within the North American plate may be generated by the same mechanism that drives the movements of large lithospheric plates. If this is indeed the case, stress measurements may furnish one of the best clues to the driving mechanism of plate tectonics.

9. A study of geotectonics of Africa is done in this study using spectral analysis of seismic signals of eight earthquakes. It is found that earthquakes on the East African rift system have lower stress drop to seismic moment ratio than those occuring off the rift system.

10. The existence of a zone of extremely low compressional wave velocities in the uppermost mantle beneath most of the Lau basin, an inter-arc basin located west or behind the Tonga island arc, is studied. This study augments the understanding of the new global tectonics that are of particular relevance to the problems of detection and identificaion of seismic events. Velocities beneath the basin appear to be as low as 7.1 km/sec. In

contrast, times of P and S waves traveling beneath and parallel to the Tonga-Kermadec ridge indicate velocities of 8.45 and 4.75 km/sec, respectively. Although the lateral boundaries of the zone of low velocity beneath the Lau basin are not well defined, they coincide approximately with the boundaries of the zone of high seismic wave attenuation that exists beneath the Lau basin. The large difference (up to 15%) between P wave velocities beneath the Lau basin and areas adjacent to it probably requires partial melting in the upper mantle beneath the Lau basin. P and S velocities measured parallel and approximately perpendicular to the Tonga trench do not differ significantly and hence provide no evidence for anisotropy in the Pacific lithosphere.

11. A study for several possible criteria for forecasting the locations of large shallow earthquakes of the near future along major plate boundaries, and for assigning a crudely determined rating to those forecasts has been conducted. This study will provide useful information about optimum siting of seismic stations and networks in reference to potential earthquake risk.

These criteria are based on the past space-time pattern of large earthquakes, the lateral extent of their rupture zones, and the direction of rupture propagation. The criteria are applied in two stages. Application of the first set of these criteria to major plate boundaries along the eastern, northern, and northwestern margins of the Pacific from Chile to Japan and also to the Caribbean loop east of about 74°W results in delineation of several areas of special seismic potential along each of the boundaries. The phrase "special seismic potential" is used in this study only to indicate those segments of plate margins that fulfill certain specific criteria. However, if the criteria are valid, at least some, and perhaps most, large shallow earthquakes of the near future within the zones examined will occur near these locations. At present, the validity of the criteria is not firmly established and profound social changes based on these predictions are uncalled for, but the forecast presented here can, at the very least, serve as a guide in selecting areas for intensive study and instrumentation prior to the occurrence of a major earthquake. In certain areas where additional information is available, the subsequent application of a second set of supplementary criteria focuses special attention on certain of the areas delimited by the first set of criteria.

Line - Item 1d

Using earthquakes recorded at LASA in Montana and at a deep mine observatory in Ogdensburg, New Jersey, phase and group velocities of mantle Love and Rayleigh waves were determined and regionalized shear-velocity models of the upper mantle were inferred. Important conclusions are: (1) Major shear-velocity differences among the different tectonic regions exist at depths less than 300 km. (2) Shear velocities in the upper mantle are markedly higher for the shield areas and lower for the tectonic areas than for the oceanic areas. The velocity difference between the shield and

tectonic models is approximately 10% at depths less than 100 km, decreasing gradually to 5% at a depth of 200 km. (3) The shield data do not require a pronounced low-velocity channel in the upper mantle, as does the oceanic model, but only a slight low-velocity channel if the Sn velocity is 4.6 km/sec. (4) The tectonic data do not necessarily require the presence of a high velocity lid just beneath the M-discontinuity. (5) Unlike the other two regions, the oceanic data clearly require a pronounced low-velocity channel. (6) The dispersion of Love and Rayleigh waves for the tectonic regions can be explained more easily by different shear-velocity structures rather than by a single isotropic-layered structure. The shear velocities inferred from Love waves are higher than those inferred from Rayleigh waves by 0.2 km/sec, the velocity differences being concentrated at depths from 150 to 300 km. This discrepancy suggests anisotropy or an equivalent laminar-melting structure, or elliptical magma pockets.

Line - Item le

1. An earthquake swarm was observed in the Blue Mountain Lake area of the southern Adirondacks from early May 1971 until late February, 1972. This swarm provided an unusual opportunity for a detailed field study of earthquakes and a determination of principal stress direction for a region within a lithospheric plate. Thousands of events were recorded, the largest of which had a local magnitude of 4.0, and was felt as far as 80 km from the epicenter. A number of earthquakes were heard as well as felt - the smaller were heard, but not felt.

Thrusting mechanisms were determined from two composite fault plane solutions. The solution for earthquakes above 2 km depth indicates faulting on a plane striking N12°W and dipping 25°E. The fault plane for the deeper events (between 2 and 3.5 km) strikes N31°E and dips 59°E.

The earthquake foci define a surface that dips gently to the east to a depth of 2 km and then steepens, in agreement with the composite fault plane solutions. There is an indication that the shallower earthquakes may not represent renewed motion on a pre-existing fault, but may mark the generation of a new fault by a regional east-west compressive stress. The deeper events may represent the extension of the shallow fault and its deflection to an existing weakness. The axis of maximum compressional principal stress for the shallow composite fault plane solution trends approximately east-west and is nearly horizontal. Geological and geophysical evidence is presented to support the hypothesis that the principal stress in a zone extending from northern New York State to southern Illinois is compressive, large, and horizontal, and trends nearly east-west.

2. Blue Mountain Lake earthquake swarm data is also analyzed to see if an anomalous change in P- and S-wave velocity occurs. Preliminary analysis revealed that an anomalous change in Vp/Vs occurs before comparatively larger earthquakes in the swarm. A remarkable change in Vp/Vs has been found before an earthquake of magnitude as small as 2.5. As detection and identification of explosions and shallow earthquakes were said to have been difficult in such a small magnitude range, the development of this study may provide a new clue to this problem.

3. The radiation for a three-dimensional problem of brittle fracture is investigated. A crack is presumed to nucleate at a point in an infinite pre-stressed elastic medium, and the crack subsequently grows steadily with subsonic rupture velocities, amintaining the shape of an ellipse. Shear stresses are relieved by the crack, and exact solutions are derived for the acceleration and stress-rate (at every point of the medium) in terms of single integrals and algebraic expressions. The solutions are evaluated analytically at wavefronts and singularities, and numerically, at different points in the medium, for different growth rates of the crack.

4. A perturbation model for triggering earthquakes is described. It introduces a perturbation function which is stationary in time and has a power spectral density. By fitting the model probability density function to a histogram of actual earthquake occurrence, information about the width of the power spectral density of perturbations can be derived. From this information, inferences about the physical nature of different perturbation functions can be made.

The tides are considered as possible admissible perturbations. It is shown that, on the basis of the earthquake data and the model considered, tides may be accepted as possible triggering mechanism for earthquakes in Southern California.

Line - Item 1f

1. The elastic radiation from an earthquake, modelled by dynamic cracking has been calculated. The elastic wave solution for a plane stress, has now been programmed in an efficient way for the IBM 1130. The output from several computer runs has shown that this mode of energy release seems to require rupture velocities which are of the order of the Rayleigh speed.

2. The excitation of normal modes by a moving source has been studied. A dynamic reciprocity theorem has been proved, which permits the calculation of normal mode excitation in the Earth by a moving double couple. The axial symmetry of a stationary source is lost, and the solution involves summation over axial order numbers.

3. Teleseismic determinations of body-wave (P,S) spectra, interpreted in terms of the Brune (1970) seismic source model, are used to estimate the parameters seismic moment (M_o) and source dimension (r) for three large, shallow, strike-slip earthquakes occurring on nearly vertical fault planes and for which the same parameters can be determined from field (F) data. These earthquakes are (1) The Borrego Mountain, California, earthquake (April 9, 1968) for which [$\overline{M}_o(P) = 10.$, $\overline{M}_o(S) = 6.6$, and $M_o(F) = 3.6$] x 10^{25}dyne-cms and [$\overline{r}(P) = 13$, $\overline{r}(S) = 21$, and $L/2(F) = 17$] kms; (2) the Mudurnu Valley, Turkey, earthquake (July 22, 1967) for which [$\overline{M}_o(P) = 9.1$, $M_o(S) = 8.5$, and $M_o(F) = 7.2$] x 10^{26}dyne-cms, and [$\overline{r}(P) = 38$, $\overline{r}(s) = 41$, and $L/2(F) = 40$] kms; and (3) the Dasht-e-Bayaz, Iran, earthquake (August 31,

1968) for which [$M_o(P) = 4.8$, $M_o(S) = 8.6$, and $M_o(F) = 18.$] x 10^{26}dyne-cms, and $\bar{r}(P) = 47$, $\bar{r}(S) = 42$, and $L/2(F) = 40$] kms. The Brune (1970)model is well-calibrated with respect to the determination of these parameters for the earthquakes considered. A minimum estimate for the radiated energy can be expressed in terms of M_o and r; this estimate is low by a factor of 3-10 with respect to the estimate obtained from energy-magnitude relations for these three earthquakes. The stress drops of these events are of the order of 10 bars.

4. Archambeau's source theory (Rev. Geophys., 1968) predicts a distinct peak in the displacement amplitude spectrum of body waves radiated into the far field. Assuming that earthquakes may alternatively be described by dislocation theory, this peak in the spectrum can occur only if either (1) different parts of the fault, but on the same side of the fault, slip in opposite directions, or (2) the fault slips back after exceeding the maximum displacement. Data at the present time do not provide strong evidence for a peak in the displacement spectrum. The peak in Archambeau's spectrum may be caused by the absence of frictional damping in his model.

5. Classical Thomson-Haskell methods have recently been extended, to obtain the asymptotic wave solution in a stratified elastic medium which has both first and second order discontinuities in the elastic parameters. These methods are used here in a discussion of the observed precursors to seismic waves P´P´. The frequency-dependent reflection coefficient R (= reflected/incident displacement amplitudes) is calculated for several models of transition regions in the Earth's mantle. To generate observable precursors to P´P´, by reflection from horizontal layering within the mantle, the thickness L of the region of transition is shown to be much smaller than has generally been supposed. This result follows from the rapid decrease in R as the transition thickness increases from zero to one wavelength. For example, R (1 second) > 2½% only if L < 4 km., even in cases of 10% total changes in velocity.

6. Rayleigh waves have been propagated into wedges by solving the equations of motion numerically. The method used is a hybrid between the finite difference and finite element methods. It is based on the fact that the usual finite difference formulae are equivalent to those obtained from linear finite elements over a triangulated rectangular net. The finite element method is then used to derive new difference formulae at points not surrounded by elements such as, for example, the apex of a wedge. Computer generated movies show the propagation of the waves around the corner, the reflected waves, and the radiation of body waves from the corner.

7. An approximate source dislocation theory (Brune, 1970) predicting the shape of the body wave spectra is critically examined. The pattern of dislocation amplitudes after the earthquake, calculated from the strong-motion accelerogram, is compared with the documented offsets along the surface fracture (Buwalda, unpublished field notes). The agreement between these two independent methods of measurement is good, suggesting that the above theory is an adequate first approximation for the spectra of body waves.

The stress variations along the fault indicate two areas of major stress concentration located near the northwestern and southeastern ends of dislocation. The stress-drops for various events varied from about ten to several hundred bars.

LIST OF PERSONNEL

Scientists:

L. A. Alsop (N/C)
K. Hamada
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P. G. Richards
L. R. Sykes
M. D. Trifunac

Graduate Students:

Y. Aggarwal
V. Cormier
S. Gregersen

Engineers:

G. Hade

Problems Encountered

None

Fiscal Status

Estimated expenses through the close of the present contract period:	$175,820.34
Total cost to completion of contract:	278,316.00

Action Required by the Government

None

Future Plans

Future plans call for the continuation of the research outlined above and in other areas specifically related to the VELA-UNIFORM program.

Scientific Papers

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Alsop, L. E., and A. E. Goodman, Numerical modeling of the propagation of Rayleigh waves in wedges, in preparation.

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Fletcher, P. J., M. L. Sbar, and L. R. Sykes, Tectonic implications of P-travel time residuals of the Cannikin explosion observed in the northeastern United States, Trans. A. G. U., 53, 1972.

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Very truly yours,

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